A digital elevation model of Guam for tsunami inundation modeling

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This is a combined bathymetric/topographic gridded digital elevation model (DEM) covering the island of Guam, Mariana Islands. It is intended for use in tsunami inundation modeling. This document describes the data sources used in producing the dataset, and the technique used to compile the grid.

Grid specifications

Horizontal datum: WGS84, decimal degrees
Vertical datum: Local mean high water (see Datum corrections section)
Grid resolution: 1/3 arc-second (approximately 10 m)
Data format: ESRI ASCII raster

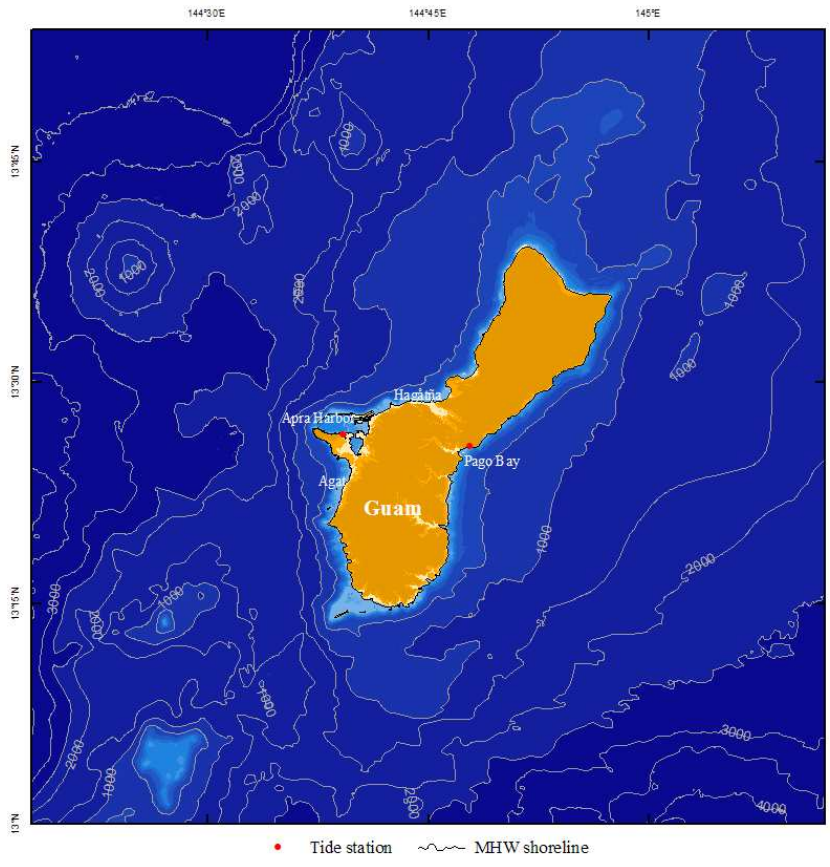

Figure 1 Guam bathymetry and topography

Data sources

The DEM was created by combining several data sources. Figure 2 shows the coverage of each data source.

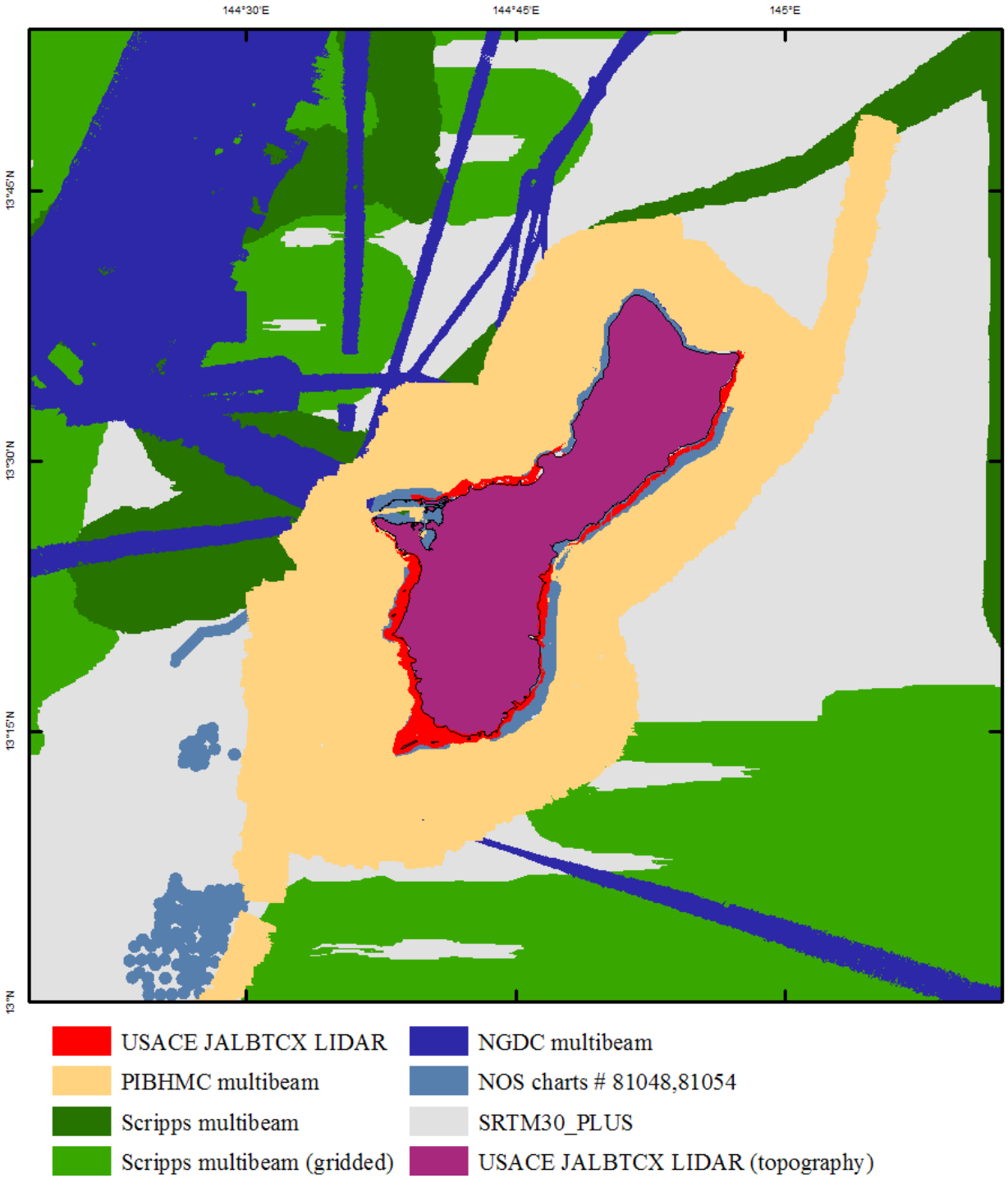

Figure 2. Overview of data sources

NGDC multibeam

The NOAA National Geophysical Data Center (NGDC) collects and archives bathymetric multibeam survey data from several sources. Bathymetric data from the following surveys were included.

Survey identifier	Source	Ship	Chief Scientist	Date
AII8L12	University of Rhode Island	Atlantis II	Ken Smith and Christian de Moustier	1987-03-30
AII8L18	University of Rhode Island	Atlantis II	Brian Taylor	1987-07-14
MGLN02MV	NOAA NMFS	Melville	Robert Embley	2006-04-20
Marianas	Korean Ocean Research and Development Institute	Onnuri	Robert Dziak	1997-09-23
OES-03-07_AHI-03-07b	NOAA NMFS	Ahi		2003-09-21
PPTU08WT	Scripps Institution of Oceanography	Thomas Washington	A. Yayanos	1986-04-22
PPTU09WT	Scripps Institution of Oceanography	Thomas Washington	H. Craig	1986-04-30
RC2610	Lamont-Doherty Earth Observatory	Conrad	Alexander Shor	1985-09-26
RC2611	Lamont-Doherty Earth Observatory	Conrad	Alexander Shor	1985-09-28
TN153	University of Washington	Thomas G. Thompson	Robert Embley	2003-02-11
TN167	University of Washington	Thomas G. Thompson	Robert Embley	2004-03-27

Limited processing was done by NCTR to clean the multibeam data. On survey PPTU08WT, all data shallower than 2400m was filtered out because it was substantially different 2001 Scripps surveys, and appeared incorrect. Surveys TUNE06WT, TUNE07WT, TUNE08WT (Scripps Institution of Oceanography, s/v *Thomas Washington*, 1991-1992) were eliminated because they were largely superseded by the 2001 Scripps surveys and 2003-2007 PIBHMC surveys (below) which appear to have undergone substantially more quality control.

Scripps Institution of Oceanography multibeam

The Scripps Institution of Oceanography at the University of California San Diego released data from a survey around Guam undertaken by the R/V Melville in March-April 2001 (survey identifier COOK07MV; chief scientist Sherman Bloomer, Oregon State University). Raw multibeam data was downloaded from Scripps's SIOExplorer site (http://siox.sdsc.edu/); plotted in dark green in Figure 2. This archive did not contain bathymetric files for several regions that were surveyed, according to the cruise report.

However, these missing data are available in gridded form from the Marine Geoscience Data System (MGDS; http://www.marine-geo.org/). These processed datasets, distributed in GMT grid format with a resolution of approximately 3.5 arc-seconds, were used where the original multibeam was not available. These regions are plotted in light green in Figure 2. The GMT grids were converted to x,y,z datasets for input to the gridding process.

Pacific Islands Benthic Habitat Mapping Center multibeam

The Pacific Islands Benthic Habitat Mapping Center (PIBHMC; http://www.soest.hawaii.edu/pibhmc/pibhmc_cnmi.htm), is affiliated with the School of Ocean and Earth Science Technology at the University of Hawaii and funded in part by the NOAA Coral Reef Conservation Program. PIBHMC released gridded bathymetric data encircling the entire island of Guam (tan color in Figure 2), derived from surveys completed between 2003 and 2007. Some nearshore regions, with depths up to 400 meters, were gridded with five-meter grid cells; the majority of the extent of the surveys was gridded with 60 meter grid cells. The higher-resolution grid points were used where available. Both grids were converted into x,y,z points for input to the gridding process.

USACE LIDAR topography and bathymetry

Data from two US Army Corps of Engineers Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) LIDAR surveys were incorporated into the grid (plotted in red in Figure 2). LIDAR is an aircraft-based laser survey system capable of collecting very high-resolution elevation data; the SHOALS LIDAR system is capable of penetrating water up to about 40 meters, and is used by the USACE to survey bathymetry in shallow waters. The first USACE survey was performed in January 2001 and collected nearshore bathymetry from roughly Hagatna Bay around the south end of the island to Pago Bay. The second USACE survey, performed February 2007, collected complete topographic data for the island as well as nearshore bathymetry from Pago Bay north to Pati Point. The horizonal positional accuracy of the LIDAR data is +/- 3 m, and the vertical accuracy is +/- 15 cm.

For the 2001 survey, NCTR used the raw SHOALS soundings in x,y,z text format as input to the gridding process. The 2007 survey was delivered as very high-resolution (1 meter) gridded datasets; point data was extracted from these for input to the gridding process. For the topography, bare-earth processing was performed by using the topographic last return gridded data. These grids were clipped using polygons provided by USACE that indicated areas where a clear ground return was detected.

NOS Raster Nautical Charts

To add data points in nearshore and shoal areas lacking high-resolution survey data, sounding points and contour lines were manually digitized from two NOAA Office of Coast Survey Raster Nautical Charts (RNC; http://nauticalcharts.noaa.gov/mcd/Raster/Index.htm), #81048 and #81054. In total, 1637 sounding points and 76 contour segments were digitized.

The nautical charts are derived from a variety of survey sources, many of them not available in digital form. Charting in most areas are primarily derived from pre-1900 surveys; parts of the west-central coast were surveyed from 1970 to 1989, but nearly all of this area is covered by higher-resolution PIBHMC and USACE LIDAR surveys. The Apra Harbor area was surveyed by the Naval Oceanographic Office in 2001 (NGDC survey identifiers W00005 and W00006), and the NOS charts were updated from these surveys.

SRTM30_PLUS

The SRTM30_PLUS dataset by Joseph J. Becker and David T. Sandwell (http://topex.ucsd.edu/WWW_html/srtm30_plus.html) is a medium-resolution global bathymetric/topographic dataset derived from satellite altimetry, ship track soundings, and other data sources. It is provided at a resolution of 30 arc-seconds, though much of the dataset is derived from lower-resolution sources, especially the 2-arc-minute Smith & Sandwell dataset. SRTM30_PLUS was used in deep-water regions of the grid where no other digital survey data was available (light gray in Figure 2).

Datum corrections

All nearshore and topographic datasets were converted to local mean high water. There are two NOS tide stations on Guam, with vertical datums as follows:

```
Station:  1630000
Name:     APRA HARBOR, GUAM

          Datum      Value (m) Description
          ---------  --------  -------------------------------------
          MHHW          1.122  Mean Higher-High Water
          MHW           1.085  Mean High Water
          MTL           0.839  Mean Tide Level
          MSL           0.826  Mean Sea Level
          MLW           0.592  Mean Low Water
          MLLW          0.407  Mean Lower-Low Water

Station:  1631428
Name:     PAGO BAY, GUAM

         Datum       Value (m) Description
          ---------  --------  -------------------------------------
          MHHW          7.960  Mean Higher-High Water
          MHW           7.922  Mean High Water
          MTL           7.745  Mean Tide Level
          MSL           7.731  Mean Sea Level
          MLW           7.568  Mean Low Water
          MLLW          7.412  Mean Lower-Low Water
```

Differences between MLLW and MHW, and between MSL and MHW, were linearly interpolated between these two points, and used to adjust the sounding data. For simplicity, the deep-water multibeam and SRTM30_PLUS datasets were not adjusted, because the adjustments involved (between 0.678m and 0.191m) were deemed insignificant relative to the deep overall soundings.

Gridding process

Gridding was performed using a two-phase process, similar to the technique developed by NGDC to develop grids for NCTR. First, a lower-resolution “pre-surface” is created with spline interpolation, then the pre-surface is combined with the higher-resolution datasets to create the final grid. This technique smooths the resulting output in areas with sparse input data points. Gridding is done with a combination of GMT (http://gmt.soest.hawaii.edu/) and MBSystem (http://www.ldeo.columbia.edu/res/pi/MB-System/) software. See below for the scripts used to process the raw data.

To create the pre-surface, the high-resolution multibeam and lidar data is gridded using MBSystem’s *mbgrid* tool to a low-resolution grid with no interpolation; this grid is converted to XYZ data points. These points, plus all of the low-resolution datapoints, are combined. This combined x,y,z dataset is median filtered by gridcells using GMT’s *blockmedian* tool, and this filtered dataset is gridded, with spline interpolation, using GMT’s *surface*. The bathymetric points from the resulting 2-arc-second pre-surface grid is converted to x,y,z points, and used as input to the final gridding.

The final gridding is done with *mbgrid*, which is capable of reading the high-resolution multibeam datasets, and processing large datasets efficiently. The presurface points are combined with the multibeam and LIDAR datasets to produce an output grid.

make_presurface script

```
#!/bin/bash

REGION=144.2/145.3/12.9/14.0
CELLSIZE=2c
SPLINETENSION=0.1

if [ "z$1" == "z" ]; then
```

```
        echo "usage: $0 basefilename"
        exit
fi
set -e

echo "output to ${1} region: ${REGION}  cellsize: ${CELLSIZE}"
echo "compile xyz points from files listed in lowres_sources.txt"
rm -f presurface/lowres_source_pts.xyz
touch presurface/lowres_source_pts.xyz
cat sources/lowres_sources.txt | while read line; do
        sourcef=sources/${line}
        wc -l $sourcef
        cat $sourcef >> presurface/lowres_source_pts.xyz
done
echo "presurface multibeam"
rm -f presurface/presurface_multibeam.*
mbgrid -A 2 -R${REGION} -E0.00111111111/0/degrees! -I sources/mb_datalist.mb-1 -F-1 -N -O
presurface/presurface_multibeam

echo "copy multibeam presurface points to xyz file"
grd2xyz presurface/presurface_multibeam.grd -S -V > presurface/presurface_multibeam.xyz

cat presurface/presurface_multibeam.xyz >> presurface/lowres_source_pts.xyz

echo "blockmedian"
blockmedian presurface/lowres_source_pts.xyz -R${REGION} -I${CELLSIZE} >
presurface/surface_source_pts.xyz

echo "surface"
surface presurface/surface_source_pts.xyz -G${1}_spline.grd -R${REGION} -I${CELLSIZE} -
T${SPLINETENSION} -V
# extract only bathymetric points
grd2xyz ${1}_spline.grd -S -V > ${1}_spline.xyz
awk '$3 < -1 { print }' < ${1}_spline.xyz > ${1}.xyz
```

make_grid script

```
#!/bin/bash

# 1 sec
#CELLSIZE=0.000277777777777777777777777777777778
# 1/3sec
CELLSIZE=0.000092592592592592592592592592592593

if [ "z$1" == "z" ]; then
        echo "usage: $0 grid_base_filename"
        exit
fi

mbgrid -A 2 -R144.3/145.2/13.0/13.9 -C1000/2 -T 1 -E$CELLSIZE/0/degrees! -I sources/datalist.mb-1 -F-1
-N -V -O $1

echo "convert to .asc..."
mbm_grd2arc -I $1.grd -O $1.asc
echo "compress"
gzip -6 $1.asc
```

Revision history

January 3 2008 – first release

January 25 2008 – update:

- add PIBHMC multibeam data
- remove NGDC multibeam TUNE* surveys; superseded by the PIBHMC data
- Replace USGS topography originally used with data downloaded directly from USGS; original data had had Z values decimated to integers

October 14, 2008 – update:

- Incorporate results from the February 2007 USACE JALBCTX LIDAR survey of the island. This survey provided complete topographic coverage of the island, allowing the replacement of USGS NED topography. The survey also added substantial new bathymetric LIDAR coverage, especially along the eastern coast from Pago Bay north to Pati Point.
- Added more digitized chart soundings in Apra Harbor, slightly improving resolution in areas not covered by multibeam.